An Improved Islanding Detection Technique and Priority Based Load Shedding for Distribution System with multiple DGs

Narayanan. K
Student Member IEEE
Dept. of Electrical Engg.
MNIT, Jaipur, India
narayanan.mnit@gmail.com

Shahbaz A.Siddiqui
Dept. of Electrical & Electronics Engg.
Manipal University, Jaipur, India
shajju77@gmail.com

Manoj Fozdar
Senior Member IEEE
Dept. of Electrical Engg.
MNIT, Jaipur, India
mfozdar.ee@mnit.ac.in

***Abstract*—The identification and operation of islands in the presence of Distributed Generation (DG) Units has become challenging. The non-detection of islanding could lead to a cascaded failure of the system. This paper proposed an Improved Islanding Detection Technique (IIDT) for early and accurate identification of the bus for islanding in the presence of multiple DG units. In the islands identified thus, a priority based load shedding scheme is proposed to alleviate the power mismatch with minimum amount of load shedding. The proposed schemes have been tested on standard IEEE 33 and 69 Bus test systems and the results obtained are promising.**

***Keywords*—Decisive Parity Coefficient, Distributed Generation, Islanding detection, Reliability Analysis, Voltage-Active Power Sensitivity.**

I. Introduction

Distributed Generation (DG) is an electric power source connected directly to the customer side of the Distribution Network (DN). The various definitions and technologies of DGs are described in [1]-[2]. The various methods and models for optimal placement of DG units is described in [3]. When the distribution system becomes electrically isolated from the power system due to abnormal conditions while being connected to the DG, is known as Islanding [4]. During the operation of the system, detection of unintentional islanding is critical as non-detection of such conditions could lead to a cascaded failure of the system. A comprehensive survey of islanding protection with renewable DG has been reported in [5]. The islanding detection techniques are broadly classified into Active and Passive techniques. The Active islanding detection schemes are difficult to implement since perturbations are introduced at regular intervals which could lead to degradation in the system performance. This leads to slow response in detection of islanding event. Most of the active IDTs are proposed for current controlled sources and for single DG unit only. Their response for multiple DG units has not been explored [6].

The passive islanding detection techniques uses local measurements of voltage, frequency, current. The passive techniques have inherent disadvantage of large Non-Detection Zone (NDZ) and require precise setting of threshold values of different parameters. If threshold values are set too low, it results in unwanted tripping and higher threshold values may result in failure of detection of islanding event. The cost of implementation of passive IDTs is less along with early detection of islanding, hence these techniques are preferred. The algorithms of passive scheme includes under/over frequency and voltage, rate-of-change of frequency and power and harmonic distortion indices [7]-[8]. Many techniques ranging from usage of voltage variations and its derivatives, frequency variations and its derivatives, etc. have been proposed for islanding detection in the presence of DGs in the system in [9]-[14].

In the islanded part of the system, the power mismatch may lead to collapse of the system if proper corrective actions are not initiated timely. Most schemes proposed in the literature use load shedding as an emergency control action to alleviate the power mismatch [15]-[18]. Majority of the proposed load shedding schemes are based on under-frequency load shedding methods. However, some under-voltage load shedding schemes have also been incorporated by researchers. Most of the existing schemes in the literature shed the loads on discrete basis to maintain power balance, this may lead to higher amount of load shedding than required. Since, load shedding also depends on economic reasons along with technical reasons, traditional load shedding schemes need to be modified for effective operation of the islanded system with minimum loss of load.

In this paper, an Improved Islanding Detection Technique (IIDT) is proposed for detection of unintentional islanding event early and accurately during the operation of the system. The proposed IIDT incorporates the existing parameters utilized in passive IDTs along with the proposed Voltage-Active Power sensitivity parameter. In order to maintain the power balance in the detected island a priority based load shedding scheme is proposed to regain the frequency and voltage stability in the islanded part of the system. To determine the effectiveness of the proposed load shedding scheme, reliability analysis is performed before and after load shedding. The proposed schemes were implemented on the standard IEEE 33

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and 69 Bus Distribution Systems. The proposed IIDT identifies the islanding event accurately and effectively as compared to existing passive IDTs. The proposed load shedding scheme, identifies the most vulnerable buses for load shedding for regaining the frequency and voltage stability in the island in the descending order of severity. The proposed load shedding scheme ensures minimum amount of load shedding in the island to regain the frequency and voltage stability in the island.

II. Proposed Improved Islanding Detection Technique

A system blackout occurs due to upstream faults or failure of grid. A major advantage of appropriate installation of DG units in the distribution system is the intentional islanded operation of the system with less amount of load shedding [19]. However, the unintentional islands may have active or reactive power imbalance leading to frequency, angle or voltage instability leading to tripping of interconnected tie-lines and resulting in instability in the interconnected parts of the network. Therefore, the unintentional islanding event has to be detected early and accurately to assist the system operator for initiating appropriate control actions to avoid a blackout of the islanded region.

In the proposed IIDT, the parameters used in the existing passive IDTs, namely rate of change of voltage, rate of change of frequency and rate of change of active power are utilized for alerting the system operator for an impending islanding event. If any of the parameters violate the pre-defined threshold limit, the islanding event is suspected and the system goes into an alert state. In the alert state, a dynamic Voltage-Active power sensitivity parameter is proposed to detect the islanding event. In the alert state if the proposed parameter violates the pre-defined threshold limits at any bus, it is classified as an islanding event and the bus is identified as the vulnerable bus. In the existing passive detection techniques the following parameters are utilized:

The variation in voltage at each bus is measured for every time instant as:

$$Voltage\ Variation = dV\ (Volts) \tag{1}$$

The voltage parameter is computed by averaging the variation of voltage over five continuous cycles. The averaging of voltage over 5 continuous cycles is performed to avoid any errors in measurement. This parameter is measured in (V/sec).

$$Voltage\ Parameter\ (\delta V_t) = |\frac{dV}{dt}| < \sigma\ for\ 5\ cycles \tag{2}$$

σ is the predefined threshold value for the parameter and is taken as 160 V/sec [11]. The frequency at each bus is monitored and the variation in frequency is calculated for every time instant as:

$$Frequency\ Variation = df\ (Hz) \tag{3}$$

The Rate Of Change Of Frequency (ROCOF) is calculated as frequency parameter at every bus for each cycle in (Hz/sec).

$$Frequency\ Parameter\ (\delta f_t) = |\frac{df}{dt}| < \epsilon \tag{4}$$

The ROCOF is used for fast islanding detection. The ROCOF is calculated over a window of few cycles, usually between 2 and 50 cycles. The typical ROCOF settings installed in 60 Hz system are between 0.1 and 1.2 Hz/sec. However, the *ROCOF* relays may become ineffective if the power imbalance in the islanded system is less than 15%. The threshold value of ϵ is set as 2.18 (Hz/sec) for 60 Hz system [12].

The net active power is monitored at each bus for every cycle. Since the power available from the DG units are constant, the variation will be less in DG buses. However, the buses farther away from the DG bus will have more effect of variation of active power when the load demand changes.

$$Active\ Power\ Variation = dP\ (MW) \tag{5}$$

The Rate Of Change Of Active Power (ROCOP) is calculated at each bus for every time instant in (MW/sec).

$$Rate\ of\ change\ of\ Active\ Power\ (\delta P_t) = |\frac{dP}{dt}| < \Lambda \tag{6}$$

Λ is the pre-defined threshold limit and is fixed as 0.64 MW/sec [12].

If any of the above parameters violate the pre-defined threshold values, the system operator is alerted for an impending islanding event and the system enters an alert state. In the alert state, if the proposed Voltage-Active Power sensitivity parameter also violates the threshold limit islanding event is identified. The Voltage-Active Power sensitivity parameter (ΔV_P)is calculated by dividing eqn. (1) by eqn. (5). This gives the variation of voltage to real power parameter at a bus and is measured in (V/MW). Since the parameter is cross-coupled, the triggering of islanding due to false tripping is avoided. The problem of NDZ is also overcome considerably by utilizing the proposed parameter for islanding detection. Mathematically it can be given as:

$$Voltage\ Active\ Power\ Sensitivity\ (\Delta V_P) = |\frac{dV}{dP}| < \mu \tag{7}$$

'μ' is the threshold value of the proposed Voltage-Active Power Sensitivity parameter the threshold value of the proposed parameter is set after extensive simulations and testing. The value of 'μ' is set at 10%. The islanding event is identified in a two-stage process. In the first step, if either the voltage parameter (δV_t) or frequency parameter (δf_t) or Rate-of-change of Active Power (δP_t) violate the predefined threshold limit, the system operator is alerted for a suspected islanding event and the system goes into alert state. In the alert state if the Voltage-Active Power sensitivity parameter also violate the threshold, it is classified as an islanding event and the bus at which the violation occurs, is identified as the islanding bus. It can be expressed as:

$$Islanding\ Detection = Alert\ State\ \&\ |\frac{dV}{dP}| > \mu \tag{8}$$

A flow chart of the proposed IIDT is shown in fig. 1.

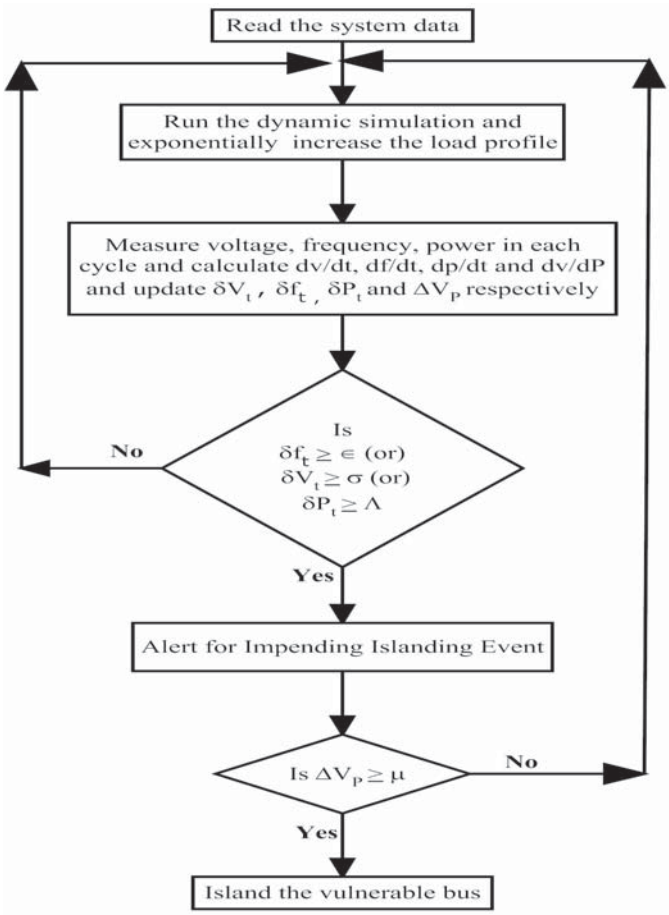

Fig. 1. Flowchart of proposed IIDT with multiple DG units

III. Proposed Priority Based Load Shedding Scheme

The operation of islands is a complex task due to the power mismatch in the island. Most of the existing control schemes utilize load shedding as a corrective measure for stable operation of the island. For maintaining the power balance in the detected island a priority based load shedding scheme is proposed. The proposed load shedding process is initiated, when the power demand exceeds the power output of the DG sources in the island. The loads are ranked on the basis of rate of change of frequency and rate of change of voltage. The bus with largest variations of frequency and voltage is the most suitable bus for load shedding. However, the variations of frequency and voltage at the DG bus are not sharp due to the presence of DG and thus the DG bus will not participate in the load shedding. All the other buses are ranked and the loads are shed until the system frequency and voltage of the buses are brought back within threshold limits. The total amount of load shed in the system is calculated on the basis of the rank and the loads in the individual buses and can be expressed as:

$$Load\ shed = DPC_i * P_{Load,i} \tag{9}$$

where $P_{Load,i}$ is the load at bus 'i', DPC is the Decisive Parity Coefficient for a particular bus and is calculated as:

$$DPC = C_i * \tau_f * \tau_V \tag{10}$$

where τ_f and τ_V are the coefficient of frequency and voltage components respectively of the buses and are calculated as follows:

$$\tau_f = \frac{f_{i,t}}{f_{init,0}} \tag{11}$$

$$\tau_V = \frac{V_{i,t}}{V_{init,0}} \tag{12}$$

where $f_{i,t}$ is the frequency at bus 'i' when load shedding is initiated, $f_{init,0}$ is the frequency of the islanding bus when the islanding is detected. $V_{i,t}$ is the voltage at bus 'i' when load shedding is initiated, $V_{init,0}$ is the voltage of the islanding bus when the islanding is detected. The value of C_i for the buses is given as:

$$C_i = \begin{cases} 0, \ if\ DG\ is\ present, \\ 1, \ if\ DG\ is\ absent. \end{cases} \tag{13}$$

Since in distribution system the load shedding is discrete in each bus, the value of C_i is taken as either 0 or 1. The frequency, voltage and power flow limits are monitored during each step of the load shedding process and mathematically expressed as:

$$f_{min} \leq f_i \leq f_{max} \tag{14}$$

$$V_{min} \leq V_i \leq V_{max} \tag{15}$$

$$P_{min} \leq P_i \leq P_{max} \tag{16}$$

The reliability of the islanded system is computed before and after load shedding to measure the effectiveness of the proposed priority based load shedding scheme. The reliability analysis is performed through standard reliability indices and from the failure rate and repair time of the lines in the system. The most commonly used reliability indices are SAIDI, SAIFI, CAIDI, ENS and AENS. These indices are commonly obtained from the customer failure statistics [20]. The quantitative reliability analysis of the system gives a measure of the effect of the proposed load shedding scheme in the system. The standard reliability indices SAIDI, SAIFI, CAIDI, ENS and AENS are calculated before and after the load shedding process to measure the effectiveness of the proposed load shedding scheme. The quantitative reliability analysis is based on the number of customers being affected, and hence the effect of the emergency load shedding schemes can be measured through standard reliability indices. The reliability indices also indicates the number of customers affected by the load shedding scheme.

A flow chart of the proposed Priority Based Load Shedding scheme is shown in fig. 2.

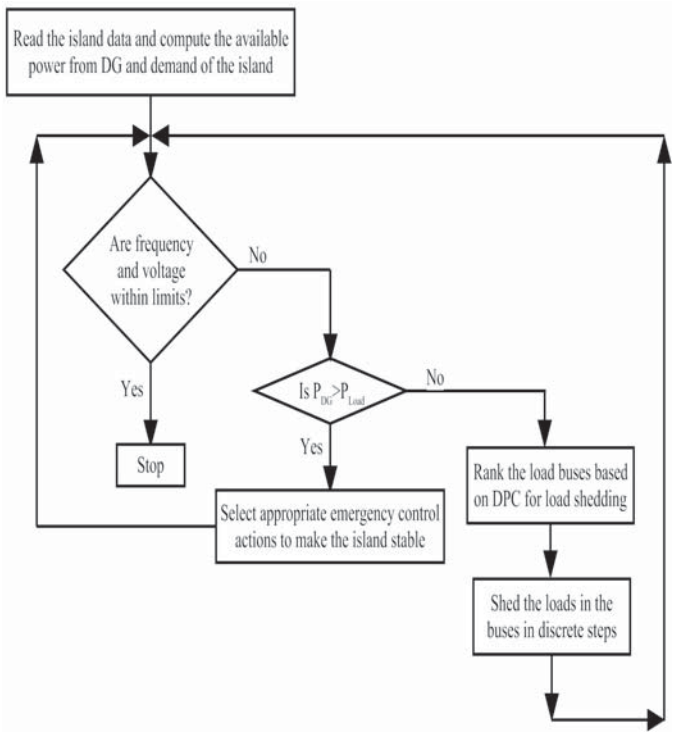

Fig. 2. Flowchart of Proposed Priority Based Load Shedding Scheme

IV. Results and Discussion

The proposed method of islanding detection has been performed on 33 bus and 69 bus standard radial systems. Three DG units are optimally installed in the system by Harmony Search Algorithm (HSA) as described in [21] for loss minimization in the 33 Bus system and 69 Bus system. The real and reactive loads are increased exponentially from base load to 160% of the base load. The observation of voltage and frequency is recorded for every time instant. All simulations have been carried out using PSAT [22] and MATLAB [23].

A. Islanding Detection by the Proposed Hybrid Method

The islanded bus and the instant of islanding by the existing passive techniques based on variation of voltage, frequency and active power are compared with the proposed IIDT. The results of islanding are shown in Table. I. It can be seen from the table that, the islanding suspicion is initiated by the Passive Method-I using variation of frequency. In the proposed method of islanding detection, the bus identified for islanding is bus 3 in the 33 Bus system and bus 6 in the 69 Bus system. In the 33 Bus system the DG units are available in buses 17, 18 and 33 respectively. The effect of variation of Voltage with Active Power cannot be more in bus number 2 which is near to the grid. The bus number 3 is the first bus vulnerable for islanding at the earliest instant, which is identified by the proposed IIDT. In the 69 Bus system the DG units are available in buses 63, 64 and 65 respectively. However, nodes upstream of bus number 6 are either zero injection bus or topologically located near to the main grid, hence are not identified as vulnerable bus for islanding by the proposed IIDT. The problem of false triggering of islanding event and NDZ in the existing passive methods are overcome in the proposed IIDT.

B. Load Shedding by the Proposed Priority Based Method and Reliability Analysis

In the islands identified by the proposed IIDT, emergency control action is undertaken to overcome the power mismatch by the proposed priority based load shedding. The proposed control action is undertaken when the power demand exceeds the power available from the DG units. The effect of the DPC parameter on the load shedding is measured when load shedding is performed without the DPC parameter. In the absence of the DPC parameter, the load shedding is initiated by shedding the loads from the buses located away from the DG bus. This requires more amount of loads to be shed to regain the voltage and frequency stability. The results of the proposed load shedding scheme in the islands is shown in Table. II. It can be seen from the table that, in both the systems, the amount of load shedding required to regain the frequency and voltage stability is more when the DPC parameter is not considered.

The effect of the DPC parameter on the load shedding is quantified by a reliability anlaysis before and after load shedding. The reliability analysis is performed with the failure data of the lines and the repair time. The reliability indices are computed before and after load shedding with and without the DPC parameter being considered. The effect of DPC parameter on the proposed load shedding scheme can be seen from the improvement of reliability indices after load shedding, shown in Table. III.

The voltage and frequency characteristics of the islanded bus before and after load shedding by the proposed priority based method for the 33 Bus system are shown in Fig. 3 and Fig. 4 respectively. The voltage and frequency characteristics of the islanded bus before and after load shedding by the proposed priority based method for the 69 Bus system are shown in Fig. 5 and Fig. 6 respectively.

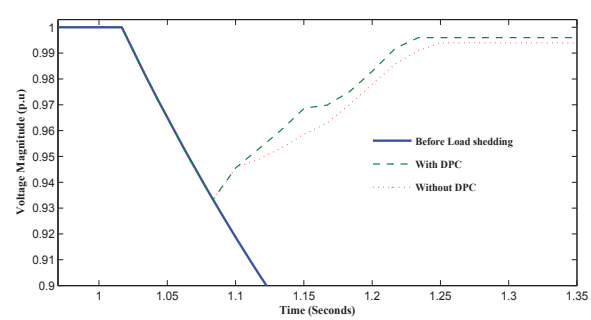

Fig. 3. Comparison of Voltage at islanded bus with DG units before and after load shedding (IEEE 33 Bus System)

TABLE I
ISLANDING ANALYSIS WITH DG UNITS

Bus System	Islanding Detection											
	Passive Method-I			Passive Method-II			Passive Method-III			Proposed Method		
	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded	Time of Detection	Islanded Bus No.	No. of Buses islanded
33 Bus System	1.058	2	32	1.084	2	32	1.074	2	32	1.058	3	27
69 Bus System	1.058	4	47	1.1162	7	40	1.074	8	39	1.058	6	41

TABLE II
LOAD SHEDDING IN ISLAND WITH DG UNITS

Bus System	Load Shedding Technique	Islanded Bus	Number of Buses in Island	Power Available (MW)	Load (MW)	Actual Load Shed (MW)	Amount of Load Shed (%)
33 Bus System	With DPC	3	27	1.875	3.255	0.72	47.82
	Without DPC	3	27	1.875	3.255	0.9	65.21
69 Bus System	With DPC	6	41	1.7732	2.5569	0.42	53.59
	Without DPC	6	41	1.7732	2.5569	0.59	75.28

TABLE III
RELIABILITY ANALYSIS OF ISLANDS WITH DG UNITS BEFORE AND AFTER LOAD SHEDDING

Bus System	Cases	Before Load Shedding					After Load Shedding				
		SAIDI	SAIFI	CAIDI	ENS	AENS	SAIDI	SAIFI	CAIDI	ENS	AENS
33 Bus System	With DPC	0.3272	0.4040	0.8099	1.38	0.0511	0.319	0.403	0.7915	0.72	0.036
	Without DPC	0.3272	0.4040	0.8099	1.38	0.0511	0.3219	0.4035	0.7983	0.9	0.05
69 Bus System	With DPC	0.1868	0.2544	0.7342	0.7837	0.0191	0.3159	0.3806	0.8300	0.42	0.0135
	Without DPC	0.1868	0.2544	0.7342	0.7837	0.0191	0.3339	0.3856	0.8661	0.59	0.02185

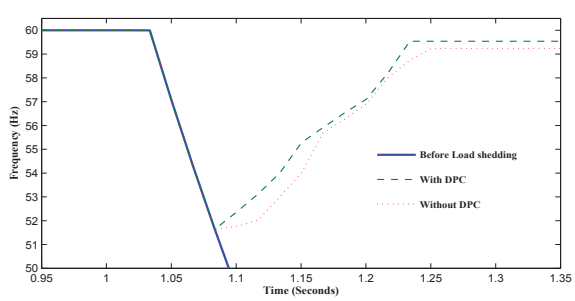

Fig. 4. Comparison of Frequency at islanded bus with DG units before and after load shedding (IEEE 33 Bus System)

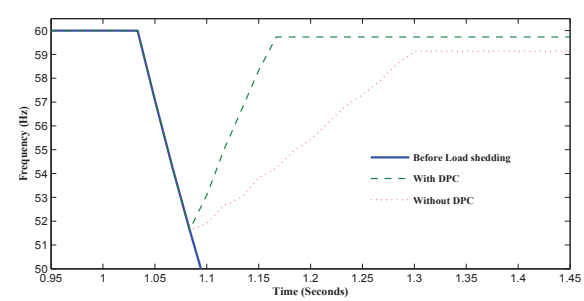

Fig. 6. Comparison of Frequency at islanded bus with DG units before and after load shedding (IEEE 69 Bus System)

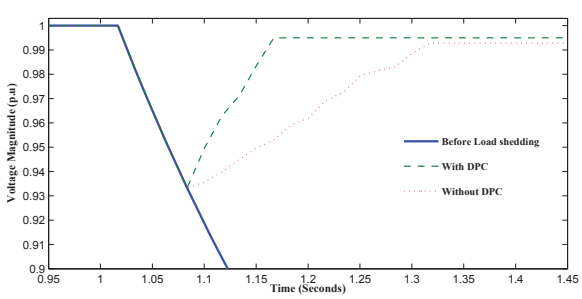

Fig. 5. Comparison of Voltage at islanded bus with DG units before and after load shedding (IEEE 69 Bus System)

V. CONCLUSION

In this paper, an additional parameter is proposed along with the existing parameters utilized in the passive IDTs, for identifying the islanding event in the presence of DG units. The additional Voltage-Active Power parameter is the variation of voltage with active power at a bus. The introduction of additional parameter ensures the system against false triggering of islanding event and as well assist to identify the vulnerable bus accurately. The proposed parameter is sensitive to sudden large load variations or disturbances due to cross-coupling of voltage and real power.

The proposed priority based load shedding in the island

uses a dynamic DPC parameter to identify the buses for load shedding. The load shed by the proposed method is less as compared to conventional load shedding strategy to regain the frequency and voltage stability in the island. The proposed DPC parameter takes into account the availability of DG unit, frequency and voltage variations in a bus before initiating load shedding. A quantitative reliability analysis of the islands, before and after the load shedding determines the effectiveness of the proposed load shedding scheme. The number of customers affected by the load shedding when DPC parameter is considered is less and the reliability indices are improved as the loads of only the vulnerable buses are shed. Since the reliability indices also depend on the number of customers being affected, the proposed DPC parameter is effective in improving the reliability of the island. These studies can be extended to investigate proper control action needed under islanded condition when the DG power available is more than the demand in the island.

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